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Costs of Firefighting Mopup Activities

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Costs of mopping up wildfires have been difficult to estimate because data are not recorded in a way conducive to separate total fire cost into components such as personnel and equipment or mobilization and demobilization of crews. To estimate costs, 25 National Forests in three Forest Service regions in the Western United States were asked in 1981 and 1982 to provide data on hours spent in mopup work. The data were analyzed by a multiple linear regression technique to predict cost estimates. Mopup estimates ranged from $772 per acre ($1908/ha) to $2391 per acre ($5908/ha). Results suggest that mopup costs are high when compared with cost estimates of other fire management activities or with total cost of extinguishing a fire.

Retrieval Terms: mopup costs, economic costs, fire economics, regression analysis

A fire management program consists of two phases—presuppression and suppression. Presuppression includes prevention, detection, initial attack, aviation operations, and fuels management. Suppression consists of a variety of activities after initial attack, including mopup (*fig. 1*). The costs of all activities in a fire management program are needed to meet the economic efficiency criterion required by the Forest Service.[1]

Mopup activities start when a fire is contained; that is, when a fireline has been built around the fire perimeter.[2] Mopup can be as thorough as needed and may vary from 100 percent extinguishment to mopup of the fire perimeter only. Of all suppression activity costs, however, mopup costs are the least available.

Mopup activities could include any or all of these actions:

- Mixing unburned and burning fuels with dirt to extinguish burning fuels.
- Digging out large roots.
- Improving constructed fireline.
- Patrolling the fire.
- Breaking up concentrations of unburned fuels next to fireline.
- Repairing damage to facilities, roads, and other resulting from suppression actions.
- Burning unburned fuels in fire islands.
- Placing water-bar tractor lines around the fire's perimeter.

Although program managers complain of the high cost of mopup activities, records are not kept in a way to easily and accurately determine the cost of mopup. Most mathematical simulations of initial attack activities stop when a fire escapes or has been contained, and mopup cost estimates are usually ignored. But to understand and evaluate current expenditure levels, analysts need to know how the monies are really spent.

This note describes a method to estimate mopup costs for analyzing the economic efficiency of fire management programs. A cost prediction equation and average mopup cost estimates for seven National Forests in the Western United States responding to the survey are provided. Results suggest that mopup costs are high when compared with other fire management activities and when compared with total cost of suppressing a fire.

METHODS

Data on hours spent on mopup activities were collected by a questionnaire[3] sent to 25 National Forests in three Forest Service regions—Northern (R-1), Intermountain (R-4), and Pacific Northwest (R-6). The National Forests contacted are within the Northern Rocky Mountain-Intermountain Climate Zone 9 (CZ-9).

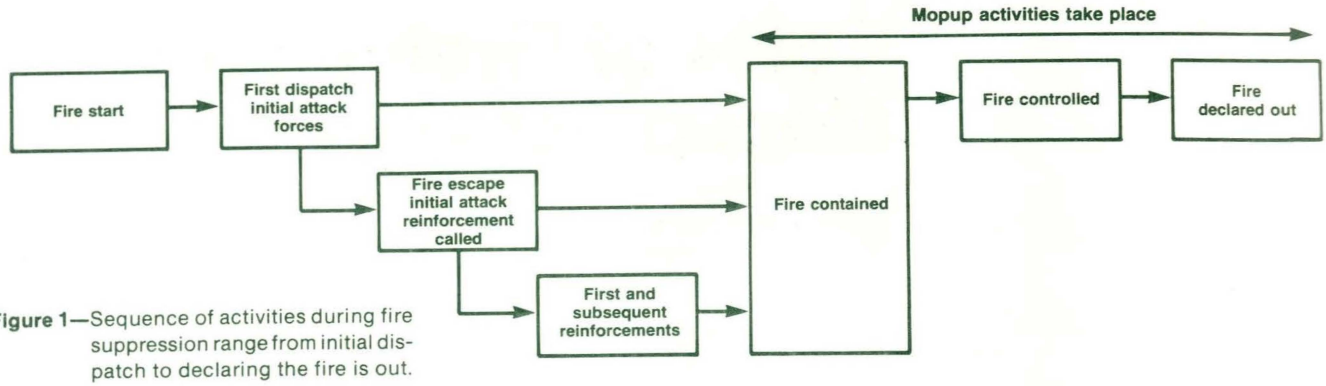

Figure 1—Sequence of activities during fire suppression range from initial dispatch to declaring the fire is out.

A climate zone is defined as an area that has homogeneous synoptic weather patterns that bring high fire damage to the area.[4] The questionnaire was pilot-tested during the 1981 fire season and a revised questionnaire was sent out during the 1982 fire season. Of the 25 National Forests contacted in 1981 and 1982, only 9 responded and, of those, 2 sent in only one observation each.

The total number of hours that fire crews spent on mopup activities on fires 1 acre (0.4047 ha) or larger were the primary data collected. In general, fires 1 acre or less require little mopup, but the northern Rocky Mountains are heavily timbered and fuel loadings are so heavy that even 1-acre fires require extensive mopup. After data on hours were collected, hourly cost estimates were used to determine the mopup cost per fire reported.[5]

To determine hourly costs, a cost-aggregation approach was used to arrive at unit cost estimates of fire management inputs (FMIs). The FMIs are various combinations of fire personnel and equipment. The cost-aggregation approach requires that individual cost components of each FMI, such as supplies, pay, or supervision are identified. Nine cost components—supplies, pay, supervision, subsistence, training, special training, overhead, equipment, and facilities—were identified for this study. Total fire season cost of each component was estimated and costs summarized to yield a total cost for the FMI. Total seasonal cost was then divided by the number of hours in the season to obtain cost per hour. The cost of all components required to place an FMI on the fireline was included in the calculation.

Regression analysis was used to develop predictions of mopup cost estimates on the basis of the sample data collected. Regression analysis is designed to identify the statistical relationships between variables. In this study, the predicted mopup cost of a fire is determined on the basis of a set of physical fire characteristics. For example, what would be the mopup cost of a 15-acre (37-ha) fire that burned in a brush area at an elevation of 5000 ft (1524 m) with a north aspect and 60 percent slope? To estimate the mopup cost of such a fire, a regression model that generates predictions is needed. A univariate multiple regression model is sufficient to analyze the problem. The prediction model developed estimates the value of mopup cost (dependent variable) given information about certain physical parameters of the fire such as fire size, slope, and elevation (explanatory or independent variables).

MODEL SPECIFICATIONS

Several combinations of 13 variables (*table 1*) were tested in the process of developing the best model for a cost prediction equation to assess economic efficiency in fire management programs. Some of the variables represent physical parameters, for example, size, slope, elevation, resistance to control, and cover type. Other variables such as FOR1-FOR6 or FOREST are used to try to measure regional differences in the mopup cost expenditures of various forests.

The original list of candidate variables included all of those listed (*table*

Table 1—*Original variables tested, their definitions, and units*

Variables	Definition	Unit
Dependent		
Cost	Mopup cost	Dollars/fire
Independent		
SIZE	Fire size	Acres burned
BI	Burning Index	Ordinal scale
SLOPE	Slope	Percent
ELEVATION	Elevation	Feet (m)
RESISTL	Resistance to control—low	Dummy variable (2 levels)
RESISTO	Resistance to control—medium to extreme	
CAUSLIT	Lightning-caused fire	Dummy variable
CAUSPER	Person-caused fire	(2 levels)
FOR1-FOR6	Forest variable	Dummy variable (6 levels)
FOR	Forest variable	Dummy variable (9 levels)
COV1-COV3	Cover type	Dummy variable (3 levels)
LNSIZE	Logarithm of fire size	(Decimals)

pile and burn). The same pattern is found on the Willamette National Forest.

When mopup costs are compared with average suppression costs developed in the Fire Economics Evaluation System (FEES) model, we find the mopup costs to be the larger component. The FEES model is a simulation model being developed by the Pacific Southwest Forest and Range Experiment Station at Riverside, California, to evaluate the economic efficiency of different fire management programs.[10] The FEES suppression estimates do not include mopup costs, so the measurement of total suppression cost would be suppression costs and mopup. Mopup costs in the Lolo National Forest, for example, are 39 percent of the total average suppression cost. A large part of the cost of putting out a fire would be incurred during the mopup phase. This fact has important implications for both fire suppression and mopup activities.

The results of this study show that mopup cost is high when compared with total suppression cost. The results suggest that it is pertinent to determine the manager's true role in determining total mopup costs. This is an area in which little research has been done and in which, by all indications, more research is needed. Better cost recordkeeping and collection methods for individual fires are needed. Expenditures can be controlled only if the true cost of each activity is known. A better understanding of the types of activities that constitute mopup would also help in determining their true cost.

NOTES

[1]U.S. Department of Agriculture, Forest Service. *FSM 5130.3—Fire suppression policy.* Washington, DC; 1981. p. 2.

[2]For a formal definition of the term, refer to U.S. Department of Agriculture, Forest Service. *FSM 5105—Definitions.* Washington, DC; 1983. p. 2.

[3]Copy of the questionnaire can be obtained on request to Armando González-Cabán, Pacific Southwest Forest and Range Experiment Station, 4955 Canyon Crest Drive, Riverside, CA 92507.

[4]Schroeder, Mark J.; Glovinsky, Monte; Hendricks, Virgil F.; Hood, Frank C.; Hull, Melvin K.; Jacobson, Henry L.; Kirkpatrick, Robert; Krueger, Daniel W.; Mallory, Lester P.; Oertel, Albert G.; Reese, Robert H.; Sergius, Leo A.; Syverson, Charles E. *Synoptic weather types associated with critical fire weather.* Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1964. 492 p.

[5]González-Cabán, Armando; McKetta, Charles W.; Mills, Thomas J. *Costs of fire suppression forces based on cost-aggregation approach.* Res. Paper PSW-171. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1984. 16 p.

[6]BMDP9R [Computer program]. In: Dixon, W. J.; Brown, M. B., editors. *All possible subsets regression in biomedical computer programs P-Series.* Los Angeles, CA: University of California Press; 1981. 80 p.

[7]Searle, S. R. *Linear models.* New York: Wiley; 1971. p. 109.

[8]McKetta, Charles W. *The analysis of fuels management costs, Lolo and Willamette National Forests projects, fiscal year 1981.* Unpublished draft supplied by author.

[9]Loveless, Robert S., Jr.; Flowers, Patrick J.; Jackson, David H.; Schuster, Ervin G. *Economic analysis of wildlife management costs in the USDA Forest Service, Northern Region.* Bull. 47. Missoula, MT: Montana Forest and Conservation Experiment Station, School of Forestry, University of Montana; 1982. 28 p.

[10]Shockley, Jo L., Program Analyst, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Riverside, CA. [Personal conversation with Armando González-Cabán]. August 10, 1983.

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Table 2—*Estimates of mopup costs for seven National Forests in Idaho, the Northern Rocky Mountain-Intermountain Climate Zone 9 (CZ-9), fiscal years 1981 and 1982*[1]

National Forest	Fire size class (acres)				Average		
	1 to 5.4	5.5 to 25.4	25.5 to 50.4	≥50.5	National Forests sampled	Northern Region (R-1)	Intermountain Region (R-4)
	Dollars/acre						
Helena	1132 (5)	1541 (1)	—	—	1397 (6)	1349 (69)	1280 (5)
Nezperce	2678 (10)	1790 (6)	—	—	1871 (16)	—	—
Clearwater	3353 (18)	1579 (3)	2849 (1)	—	2391 (22)	—	—
Lolo	1398 (15)	1270 (2)	347 (2)	705 (1)	772 (20)	—	—
Kootenai	1217 (5)	—	—	—	1217 (5)	—	—
Challis	1406 (3)	—	—	—	1406 (3)	—	—
Sawtooth	1770 (1)	937 (1)	—	—	1235 (2)	—	—

[1]Values in parentheses are fires sampled.

MOPUP COST ESTIMATES

Average mopup costs in dollars per acre for seven of the nine National Forests within Climate Zone 9 responding to the survey varied (*table 2*). The forest-wide averages ranged from a low of $772 per acre ($1908/ha) in the Lolo National Forest to a high of $2391 per acre ($5908/ha) in the Clearwater National Forest.

Mopup costs among forests varied also. The variation is difficult to explain in terms of the physical parameters of fires and surrounding areas. Variation in costs may have more to do with differences in management approaches and standards. Because formal Forest Service mopup standards are uniform, however, the possible explanations for the cost differences include degree of compliance, management style, level of skills, and attitudes toward risk. Managers who are less risk-sensitive should have lower mopup costs because they probably would commit the minimal amount of resources to mopup. But risk-sensitive managers may want to put as many resources as possible on mopup to prevent a fire escape. The availability of forest firefighting funds (FFF) to pay for mopup activities may be another source of the variation.

Findings in other areas of fire research help to make the managerial influence hypothesis credible. A fuel cost treatment study completed recently showed that only a few physical parameters were significant cost determinants.[8] Most cost determinant variables were proxies for management variables. Another study on the economic analysis of wildlife management costs in the Forest Service, Northern Region, expressed the same concerns.[9]

Because the management variable appeared in all three studies may indicate that a better approach is needed to measure the effects of management on project costs. Predicting total project costs in terms of only physical parameters probably will lead to underestimated costs and poor predictions.

Table 3—*Cost estimates for different fire suppression activities on eight National Forests in the Northern Rocky Mountain-Intermountain Climate Zone 9 (CZ-9), fiscal year 1981 (1978 dollars)*

National Forest[1]	Fuel treatment[2]			Average suppression cost[3] 0 to 100 acres	Average mopup cost
	Broadcast burning	Hand-pile and burn	Bulldozer-pile and burn		
	Dollars/acre				
Lolo	322	589	128	930	594
Willamette	521	334	175		—
Helena					1075
Nezperce					1439
Clearwater					1840
Kootenai					936
Challis					1082
Sawtooth					950

[1]All National Forests listed are in Idaho except Willamette, which is in Oregon.
[2]Source: McKetta (1983).
[3]Source: Shockley (1983).

RESULTS AND DISCUSSION

Average mopup costs compared with other fire management cost estimates including fuel treatment and fire suppression showed that mopup costs are significantly high in relation to the other estimates (*table 3*). When compared with the cost of fuel treatment for hazard reduction, for example, the significance of the mopup costs is evident. The most expensive fuel treatment estimates are $589 per acre ($1455/ha) on the Lolo National Forest for hand-pile and burn. This is only $5 less than the mopup cost in the same forest. When compared with bulldozer-pile and burn, mopup costs are four and one-half times larger than fuel treatment costs ($594 per acre [$1468/ha] mopup as against $128 per acre [$316/ha] bulldozer

and all possible interactions between them. Because of too many variables and interaction terms in the list, however, not all possible subset regressions could be evaluated. The overall list was then screened to eliminate less useful variables. A variety of exploratory techniques was used, such as evaluating relative contribution of R^2 for various subsets, and generating random explanatory components into the data set. In this manner, an initial set of manageable size was obtained from which to choose the best model. The initial set was evaluated in terms of all possible subset regressions by the Biomedical Computer Programs statistical software package.[6] The resulting set of explanatory variables included SIZE, COV1, LNSIZE, BI*COV1, SIZE*EL, SIZE*COV2, and BI*CAUSE.

The best model has greater explanatory power and better predictive capability than all other models tested (equation 1). Values in parentheses are "t" values.

$$\begin{aligned}\text{Mopup cost} = {} & 2807 + \underset{(2.72)}{} 3775\ \text{SIZE} - \underset{(11.01)}{} 85249\ \text{COV1} + \underset{(-4.37)}{} 1929\ \text{LNSIZE} + \underset{(2.10)}{} 1752\ \text{BI*COV1} \\ & \underset{(4.45)}{} \\ & - 0.29\ \text{SIZE*EL} - \underset{(-4.85)}{} 1656\ \text{SIZE*COV2} - \underset{(-6.17)}{} 109\ \text{BI*CAUSE} \\ & \underset{(-1.99)}{}\end{aligned} \quad (1)$$

$R^2 = 0.82$

Adjusted $R^2 = 0.80$

Standard error of estimate = 7132

An adjusted R^2 of 0.80 means that 80 percent of the total variation of the dependent variable (mopup cost) is explained by the regression equation. This model fits the definition of the best model: the model with the smallest variance relative to the number of variables. All regression parameters are significant at the 95 percent confidence level. The regression model performed well on predicting mopup cost for 13 new observations collected in Fiscal Year 1983.

Four interaction terms are included in the equation. All interaction terms are multiplicative; that is, they result from multiplying two variables. Although some variables by themselves do not influence mopup cost of a fire, they become significant when in combination with some other variables. Because all variables can be measured with precision, we need not be concerned with effects of measurement error on the prediction. Equation 1 can be used to predict the mopup cost for any fire.

The estimated equation was applied to the following sample fire outside the original data set:

Variable:	Unit
Fire size	2 acres (5 ha)
Burning Index	40
Elevation	4500 ft (1372 m)
Cause: lightning	1
Cover type	2
LNSIZE	0.693147

The predicted mopup cost estimate for the fire was \$2981 with a standard deviation of \$7152. The observed value was \$2628.

How the pattern of nonresponse—9 forests out of a total 25—affected the sample is not known; therefore, only approximate confidence intervals for future predictions from the regression model can be derived. If we assume the sample is representative of the range of circumstances on CZ-9 forests in general, the bounds on predictions from the model should provide a reasonable guide to the prediction precision.

The standard deviation of the prediction estimate is given by

$$[s \cdot e \cdot e^{**2} + \hat{\sigma}^2]^{1/2}$$

$$= \hat{\sigma}\,[x'(X'X)^{-1}x + 1]^{1/2} \quad (2)$$

in which $\hat{\sigma}^2$ is the mean square error from the model using the data, x is the data vector for the prediction (values of the independent variables), and X is the data matrix with which the model was developed. Estimating equation 2, we find the standard deviation for the sample fire to be \$7152 ($[535.80^2 + 50{,}868{,}811]^{1/2}$).

The prediction or tolerance interval[7] for the predicted observation is given by

$$\hat{Y} \pm t\,(N-p, \alpha/2)\,\hat{\sigma}$$

$$[x'(X'X)^{-1}x + 1]^{1/2} \quad (3)$$

in which Y is an estimate of a future observation to be made from the model, N is the sample size, and p is the number of independent variables in the model including the intercept term. Then the 95 percent prediction (tolerance) interval for the sample fire is

$$\hat{Y} \pm t\,(67, 0.025)\,(7152) = 2981$$

$$\pm 2\,(7152) = (-11323, 17285)$$

Because it is impossible to incur negative costs, the prediction interval for the equation goes from 0 to 17285.

If we consider an unlimited number of predictions from this model, the correct simultaneous tolerance interval to cover such predictions is

$$\hat{Y} \pm [pF\,(p, N-p, \alpha)\,\hat{\sigma}^2$$

$$(x'(X'X)^{-1}x + 1)]^{1/2} \quad (4)$$

Because

$$[pF\,(p, N-p, \alpha)]^{1/2}$$

$$= [7F\,(7, 67, 0.05)]^{1/2} = 3.83$$

the tolerance interval for the sample fire is

$$Y \pm 3.83\,(7152)$$

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